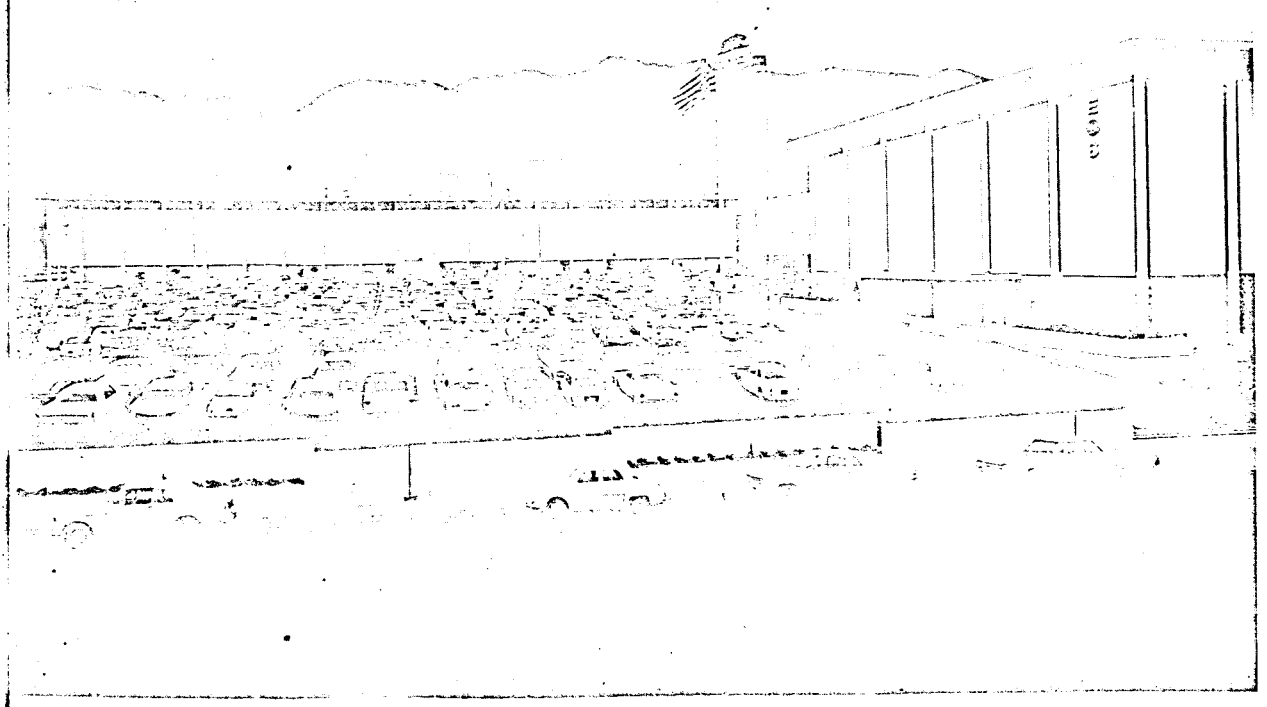
ELECTRO-OPTICAL SYSTEMS, INC.
A Subsidiary of Xerox Corporation
300 N. Halstead St., Pasadena, California, 91107 • Area Code 213 681-4671, 449-1230



HYDROGEN-OXYGEN ELECTROLYTIC REGENERATIVE FUEL CELLS

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio
Attention: D. G. Soltis

Contract NAS3-2781

EOS Report 4110-ML-37 10 July 1967

Prepared by
Robert F. Astrin
Martin G. Klein

Approved by

W. Menetrey, Manager
Power Systems Division

ELECTRO-OPTICAL SYSTEMS, INC.- PASADENA, CALIFORNIA
A Subsidiary of Xerox Corporation

CONTENTS

1.	INTRODUCTION	1
2.	TECHNICAL DISCUSSION	2
	2.1 Single Cell Tests	2
	2.1.1 Single Cell Matrix Testing	2
	2.1.2 H_2 Concentration Cell	10
	2.1.3 Reference Cells	10
	2.2 Matrix Fabrication and Screening	13
3.	PLANS FOR THE NEXT PERIOD	21
4.	FINANCIAL STATEMENT	22

ILLUSTRATIONS

1	Cycling Performance of Cell No. 269	6
2	Cycling Performance of Cell No. 274	8
3	Cycling Performance of Cell No. 282	9
4	Cycling Performance of Cell No. 276	11
5	Cycling Performance of H_2 Concentration Cell No. 265	12
6	Charge Polarization of Reference Cell No. 280	14
7	Discharge Polarization of Reference Cell No. 280	15
8	Reference Cell No. 280, Cycle No. 2	16
9	Reference Cell No. 280, Cycle No. 3	17
10	Reference Cell No. 280, Cycle No. 4	18

SECTION 1

INTRODUCTION

This report reviews the progress made on the development of a hydrogen-oxygen (H_2-O_2) regenerative fuel cell (secondary battery) under NASA Contract NAS3-2781 during the period 1 June 1967 through 1 July 1967. During this period, primary emphasis was placed on the testing of single cells with matrix structures of potassium titanate, Teflon, and asbestos. Reference cells were assembled and tested. Fabrication is progressing on the 28-volt 500-watt Flight Prototype Fuel Cell assembly.

SECTION 2

TECHNICAL DISCUSSION

2.1 SINGLE CELL TESTS

Ten single cell tests were conducted during this period to evaluate matrix and electrode configurations. Test results and construction variables of these cells are summarized in Table I.

2.1.1 SINGLE CELL MATRIX TESTING

A matrix was made by forming a rolled 0.030 KT-Teflon composite on each side of a membrane (50 percent KT, 50 percent Teflon pasted on 100 mesh screen). The matrix was assembled in cell 269 with a 0.060 spacer and 56.1 gm of 40 percent KOH. Both the EOS and Cyanamid electrodes were used in a previous cell. The cell has ran 676 cycles and the test has been discontinued. As can be seen in Fig. 1 there was little performance degradation in the first 300 cycles. Subsequent performances however fell off more rapidly. Upon disassembly the final KOH was found to be 35%. The performance drop cannot be from KOH consumption. No asbestos was used in this cell so one variable is eliminated. The remaining factors can be Pt migration and/or presence of other impurities in both the KT and Teflon.

TABLE 1

Cell No.	Electrode	Matrix	Electrolyte	Spacer (Inch)	Comments
265	H_2 EOS O_2 EOS Both new and treated for one hour in 40% KOH.	50/50 KT and Teflon pasted membrane sandwiched between 2-90/10 KT and AB mats.	40.0g of 39.7% KOH	0.060	Reversing current cycling H_2 gas concentration cell. Cell has run 1590 cycles. Test still in progress. Test temperature 80°.
269	H_2 EOS O_2 Cyanamid Both used in run #254.	50/50 KT and Teflon pasted membrane sandwiched between 2-80/20 KT and Teflon rolled composite.	56.1g of 40% KOH	0.060	Performance good through cycle 300. Subsequent cycles show a steady degradation in performance. Test discontinued after 670 cycles. Final KOH 35.5%.
274	H_2 EOS O_2 Cyanamid Both used in runs #263, 270 and 272.	Pressed KT, asbestos Teflon composite.	47.0g of 40.3% KOH	0.050	Excellent performance through cycle #394. Subsequent cycles show degradation in performance. Total cycles 736. Test still in progress.
276	H_2 EOS O_2 Cyanamid Both new and treated for one hour in 40% KOH.	80/20 KT and Teflon composite membrane sandwiched between 2-90/10 KT and AB mats.	45.1g of 40.3% KOH	0.060	Duplication of cell #266. Cell has run 344 cycles with good performance. Test still in progress.

TABLE 1 Continued

Cell No.	Electrode	Matrix	Electrolyte	Spacer (Inch)	Comments
277	H_2 EOS O_2 Cyanamid Both new and treated for one hour in 40% KOH.	50/50 KT and Teflon pasted membrane sandwiched between 2-90/10 KT and AB mats.	44.5g of 40.3% KOH	0.060	Reference Cell. Cycle 5 through 13. Showed a fast self discharge. Test discontinued.
278	H_2 EOS O_2 Cyanamid Both new and treated for one hour in 40% KOH.	50/50 KT and Teflon pasted membrane sandwiched between 2-80/20 KT and Teflon rolled composites.	37.2g of 40% KOH.	0.060	Duplication of run #269. Cross leakage of gases.
279	H_2 EOS O_2 Cyanamid Both new and treated for one hour in 40% KOH.	50/50 KT and Teflon pasted membrane sandwiched between 2-80/20 KT and Teflon rolled composites.	25.8g of 40% KOH	0.060	Duplication of run #269. Cross leakage of gases.
280	H_2 EOS O_2 Cyanamid Both used in run #277.	50/50 KT and Teflon pasted membrane sandwiched between 2-90/10 KT and AB mats.	45.3g of 39.5% KOH	0.060	Reference cell. Cell shows good performance through cycle #55. 0.015"nickel wire was substituted for 0.020" nickel wire. Test still in progress.
281	H_2 EOS O_2 Cyanamid Both used in runs #279 and 281.	50/50 KT and Teflon pasted membrane sandwiched between 2-80/20 KT and Teflon rolled composited.	24.3g of 40% KOH	0.040	Duplication of run #269. Cross leakage of gases.

TABLE 1 Continued

Cell No.					
282	H_2 EOS O_2 Cyanamid Both used in runs #279 and 281.	Pressed KT, asbestos teflon composite.	52.0g of 39.5% KOH	0.050	Duplication of run #274. Cell has run 30 cycles. Performance excellent. Test still in progress.

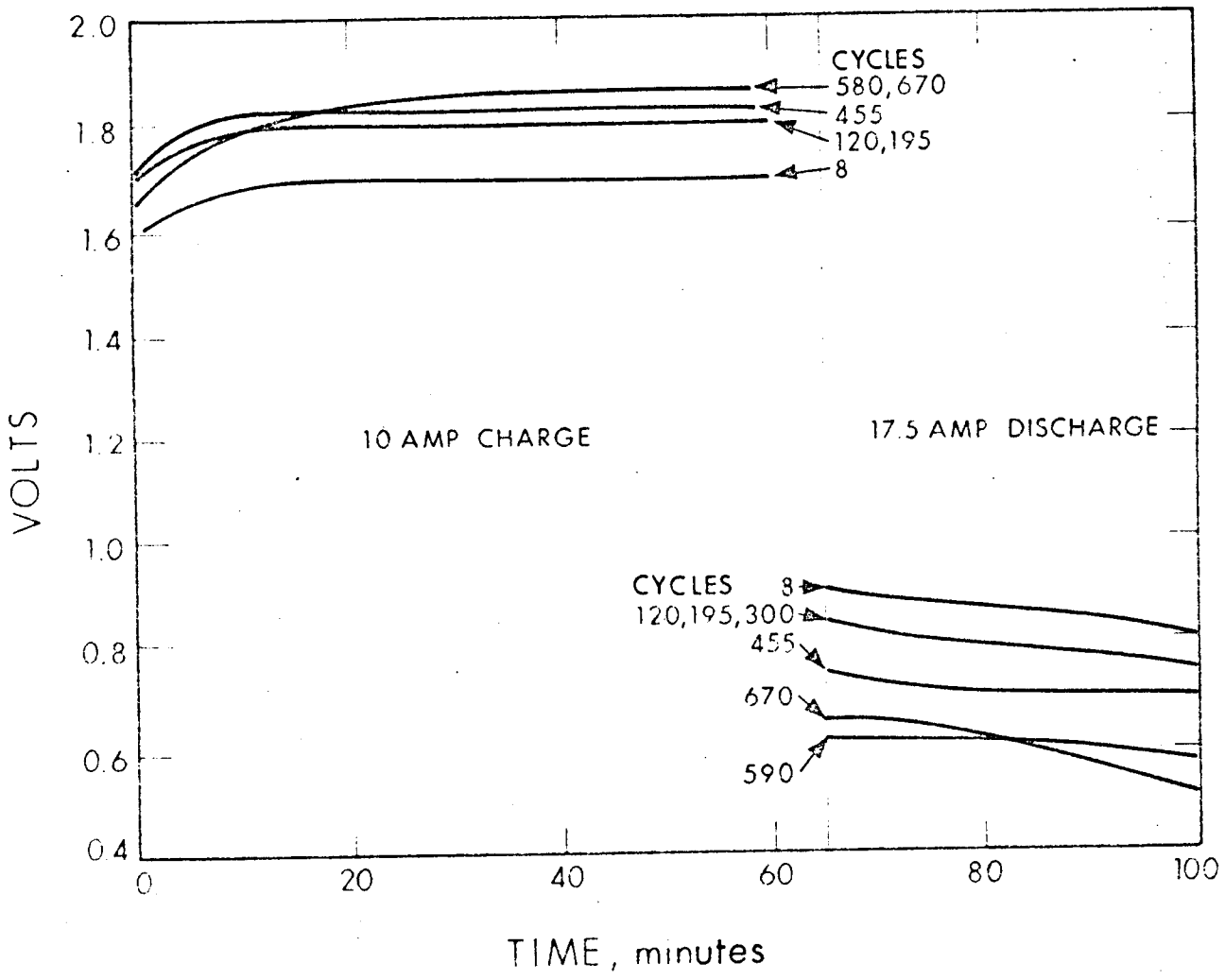


Figure 1. Cycling Performance of Cell No. 269

Cells #278, #279 and #281 were attempts to duplicate cell #269 aforementioned. The matrix allowed cross gas leakage to occur. Bubble-through testing showed the formulated batch these matrixes were made from to be defective.

A pressed composite matrix was fabricated with KT, asbestos and Teflon and successfully laboratory tested. Another matrix 0.060 inch thick was fabricated. It was assembled in cell #274 with 47.0gm of 40.3 percent KOH electrolyte and a 0.050 inch spacer. The EOS and Cyanamid electrodes have been used in previous cells. The cell has run a total of 731 cycles and is still cycling. Figure 2 shows that the performance was most excellent, 0.9 volt and above for the first 400 cycles. The performance may have been helped by the closer spacing, 0.050 inch. The subsequent performance has degraded to below 0.8 volt. The latter cycles indicate extreme flooding may be occurring. Cycling of this cell will continue in order to further observe the effects of cycle life with this type of matrix.

Cell #282 is a duplicate of cell #274 above. The matrix is a pressed composite of KT, Teflon, and asbestos. The electrodes are the usual EOS/American Cyanamid configuration. The cell has run a total of 30 cycles and is still cycling. Figure 3 shows the initial performance to be excellent (0.96 to 0.95 volt discharge) as was the initial 400 cycles of cell #274 above.

The matrix configuration of cell #276 is similar to cell #266. A 0.040 KT and Teflon composite rolled membrane was fabricated then sandwiched between two 0.020 KT-asbestos mats. This matrix contained 45.1 gm of 40.3 percent KOH and was installed with a 60-mil spacer in cell #276. The cell contained the usual EOS/American Cyanamid electrodes. The cell has run a total of 344 cycles and

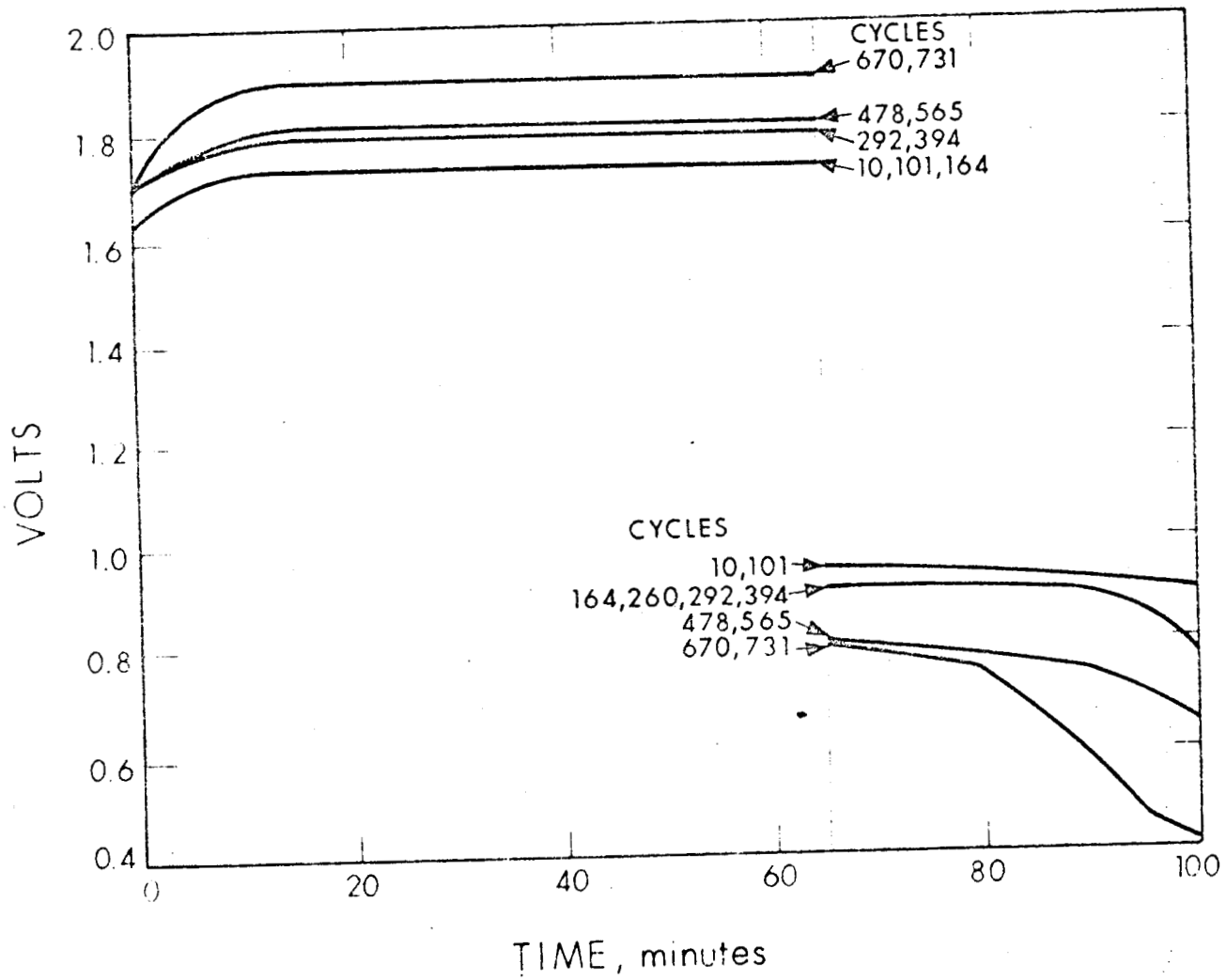


Figure 2. Cycling Performance of Cell No. 274

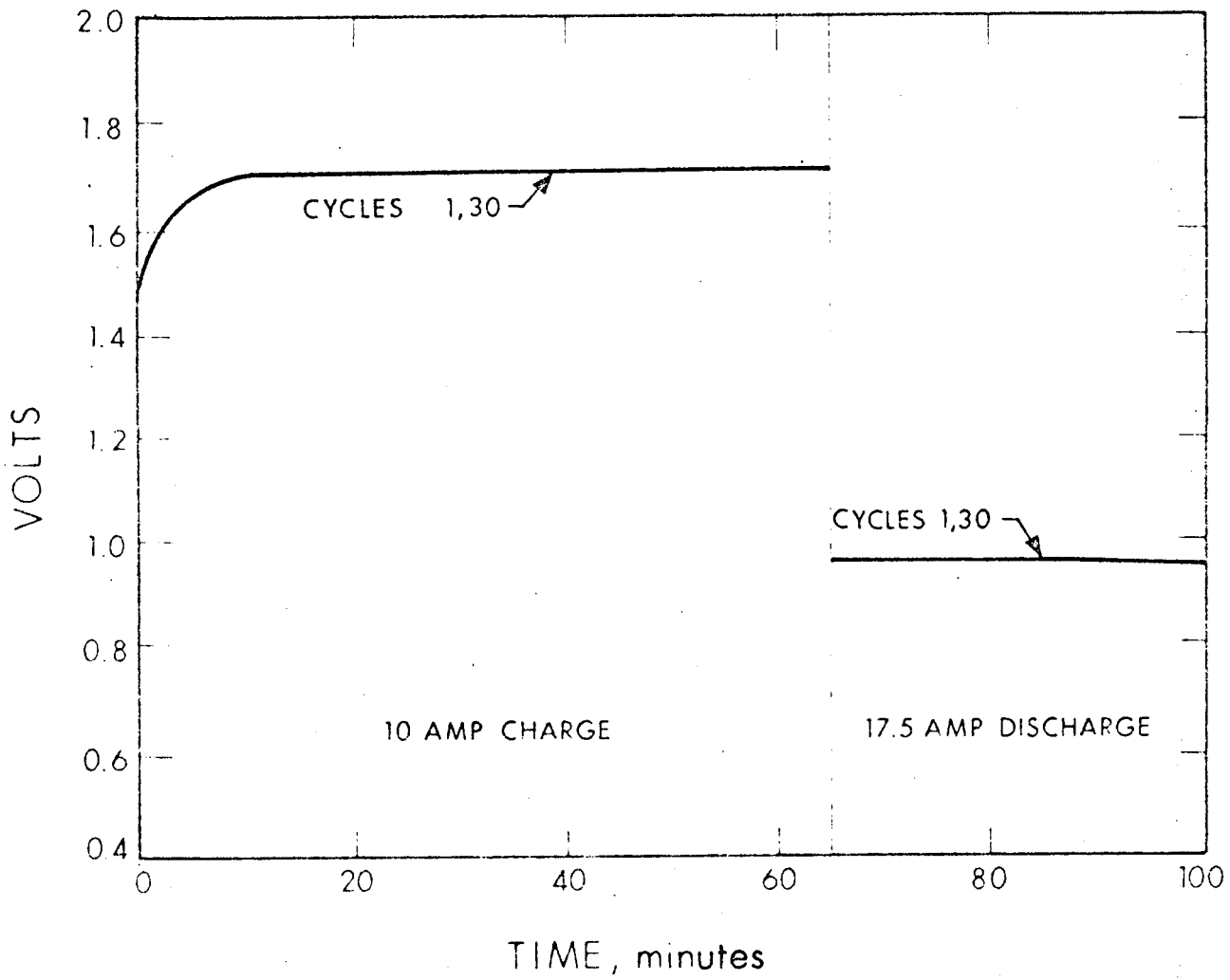


Figure 3. Cycling Performance of Cell No. 282

is still running. As can be seen in Fig. 4, the performance is good, above 0.8 volt on discharge, and performance degradation is slow.

2.1.2. H_2 CONCENTRATION CELL

Cell #265 is a cycling hydrogen concentration cell. It contains two EOS H_2 electrodes and has a 50 percent KT-50 percent Teflon membrane sandwiched between two 90 percent KT-10 percent asbestos mats. All the KT was treated in 100°C KOH for one hour and washed with distilled H_2O. The matrix contains 40 gm of 39.7 percent KOH. A 60-mil spacer is being used. The cell was flushed with H_2 gas when 150 psi of H_2 was introduced. A cycle of 18 amp charge for 35 minutes was set up. The cell has run 1711 cycles to date, and is still running. Figure 5 shows the performance. The voltage has slowly risen to around 0.35 volts and may have stablized.

2.1.3 REFERENCE CELLS

In order to characterize the American Cyanamid and EOS electrodes used in the EOS fuel cell, reference cell testing is being continued. Cell #277 contained an AB6 American Cyanamid oxygen electrode and a standard EOS electrode (of 20 mg Pt/cm^2). The matrix was made of a pasted KT-Teflon membrane sandwiched between two 90 percent KT and 10 percent asbestos mats. On each side of the membrane was placed a mercuric oxide (HgO) reference electrode. The reference electrodes consisted of nickel screens on which HgO powder was pressed. Each screen had a nickel wire spot welded on one end; the wire was fed out through the 60-mil insulating spacer. Reference cell #277 ran five cycles then began to self-discharge. The cause of failure is probably due to depressions caused by the 0.020 inch thick reference wires which are fed into the cell through the matrix.

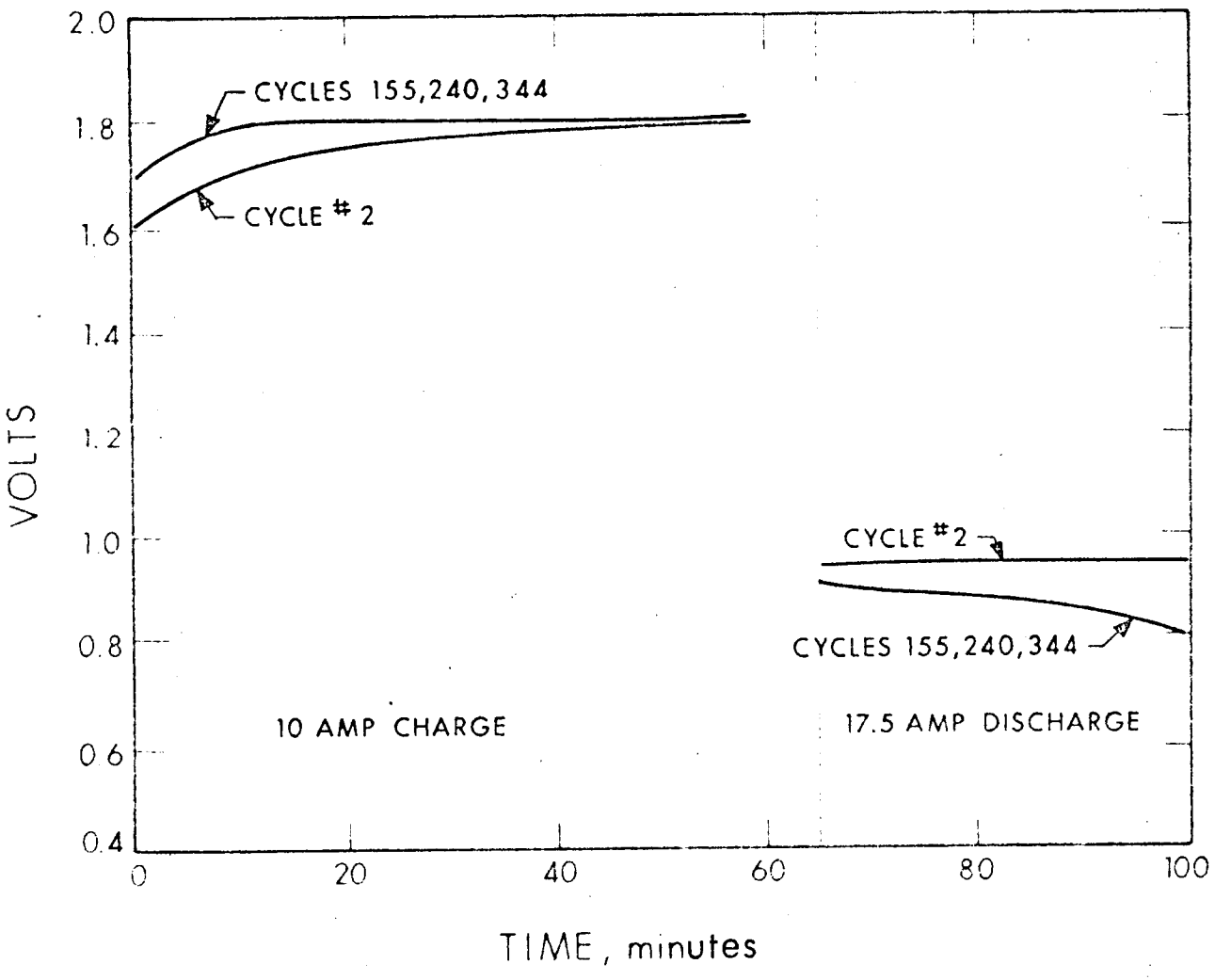


Figure 4. Cycling Performance of Cell No. 276

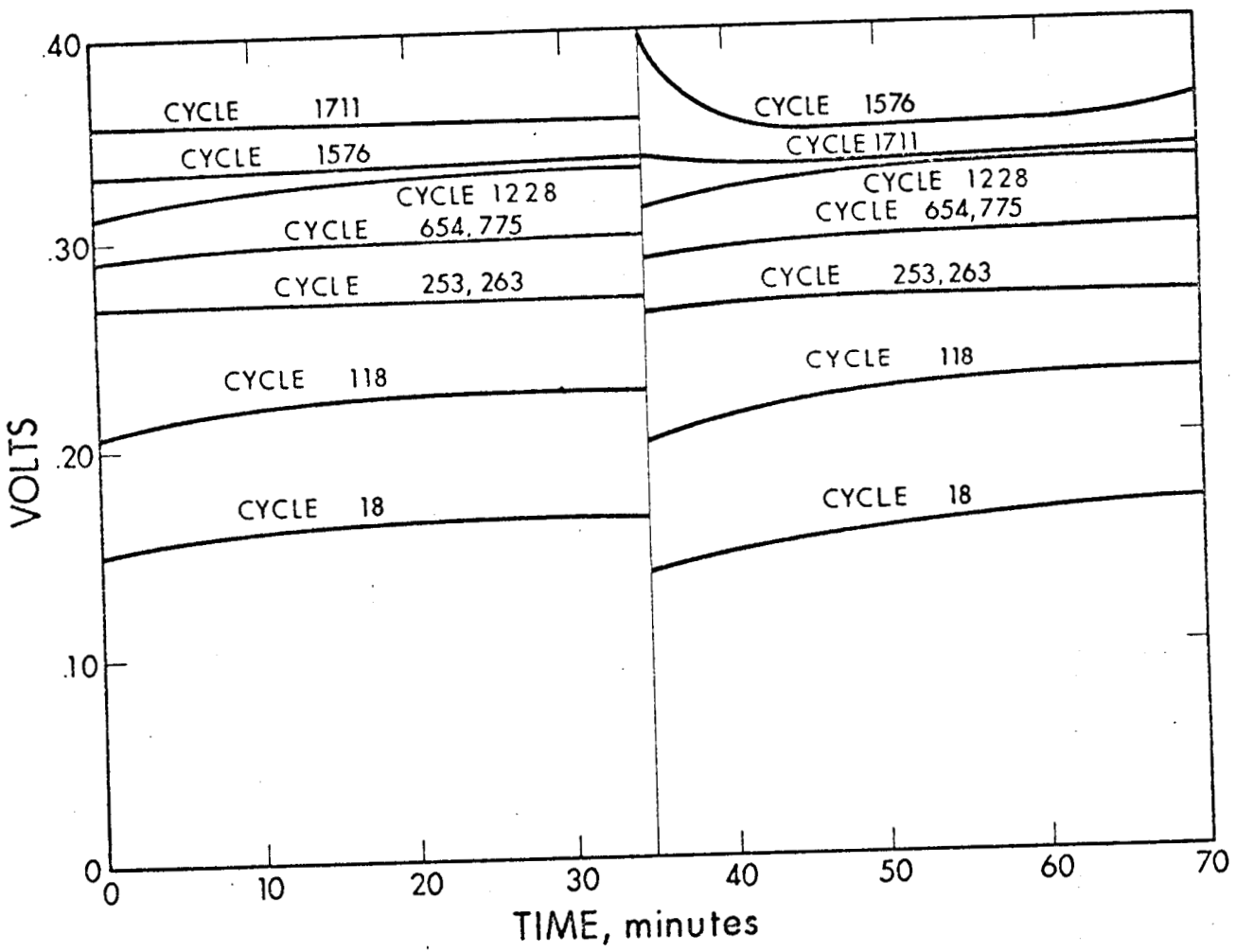


Figure 5. Cycling Performance of H_2 Concentration Cell No. 265

In the future, attempts will be made using thinner wires.

Another reference cell, #280, was built in the same manner as above except 0.015 inch thick feed-through wire was used for the reference electrodes. The cell has run 55 cycles and demonstrated good performance. The test is still in progress. Figures 6 and 7 show the initial polarization curves on charge and discharge for this cell. Figure 6 shows that the major polarization loss occurs at the O_2 electrode during charge. The largest component of polarization, a combination of activation and IR effects, is shown by the initial steep rise of the O_2 reference curve. Figure 7 shows that the largest polarization loss is observed at the initial slope of the O_2 reference curve again showing activation polarization. After a current density of about 80 mA/cm^2 the polarization losses are equally contributed by both the H_2 and O_2 electrodes since then their slopes are nearly equal. Figures 8, 9 and 10 respectively show reference readings of cell #280 cycled at 18 amps discharge, 10 amps charge and 10 amps discharge, 10 amps charge and 18 amps discharge. All the cycles were extended beyond the normal charge and discharge limits in order to observe the effects of drying and flooding on the electrodes. As can be seen in Figs. 8, 9 and 10 the largest effect caused by drying is an increase in the cell impedance. By again referring to Figs 8, 9 and 10 it is learned that during flooding the O_2 electrode is most adversely effected.

2.2 MATRIX FABRICATION AND SCREENING

Fabrication of composite matrixes using KT, polypropylene and Teflon pressed together was explored during this period. Table II summarizes the screening test results. Sample M5, composed of 95% KT, 5% polypropylene pressed one half hour at 124 psig, gave the highest bubble-through result of 25 psig. M-6 and M-7 both had

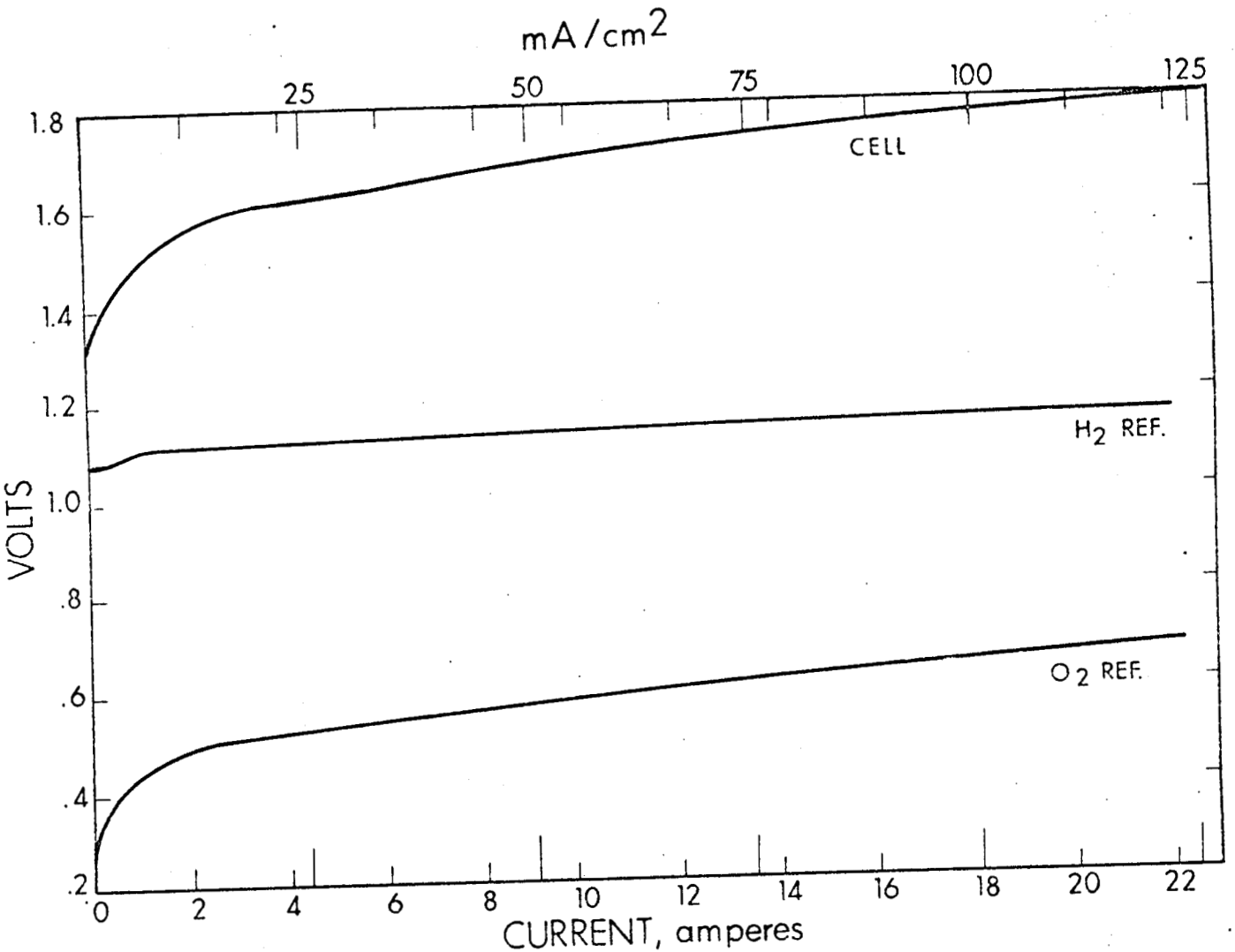


Figure 6. Charge Polarization of Reference Cell No. 280

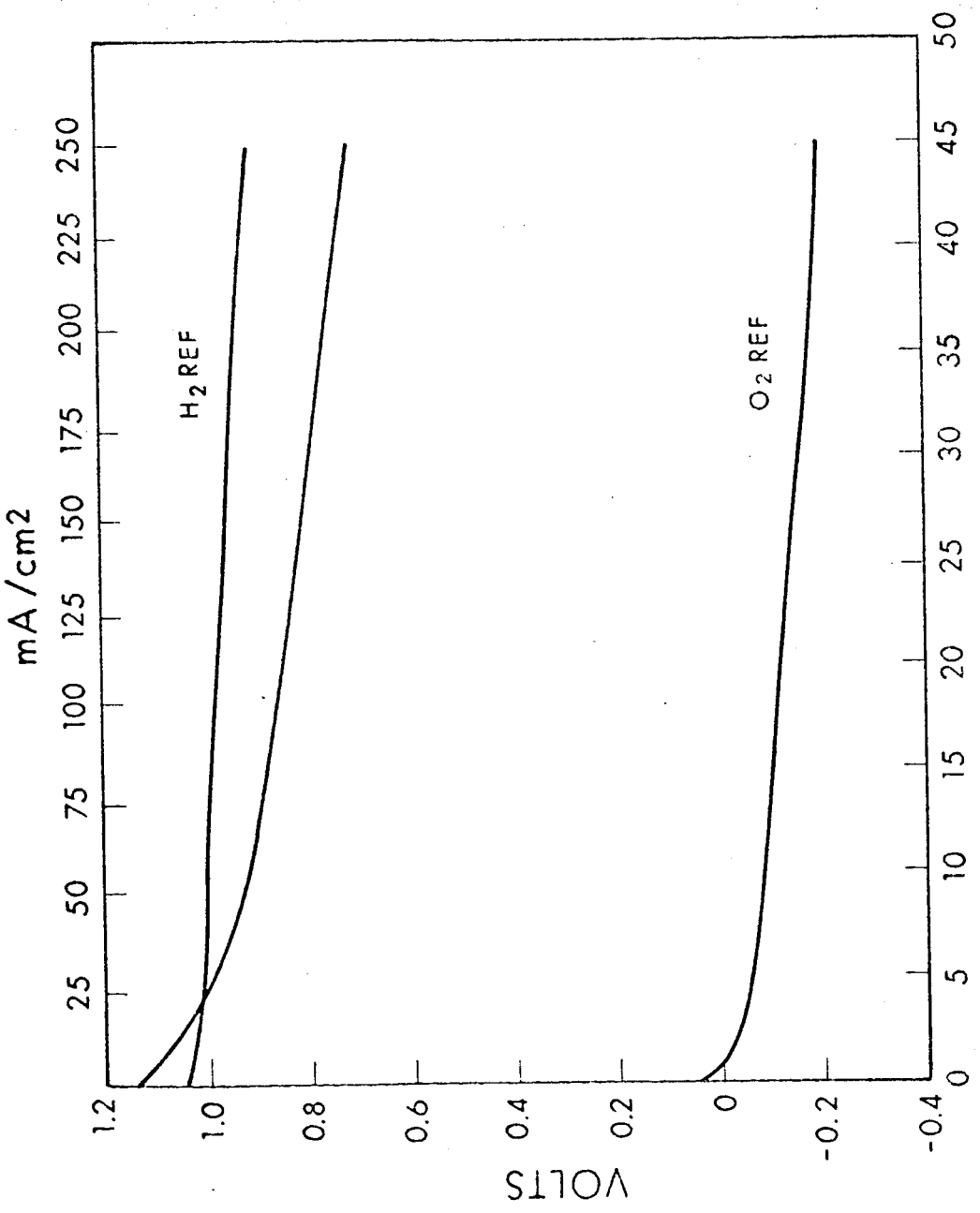


Figure 7. Discharge Polarization of Reference Cell No. 280

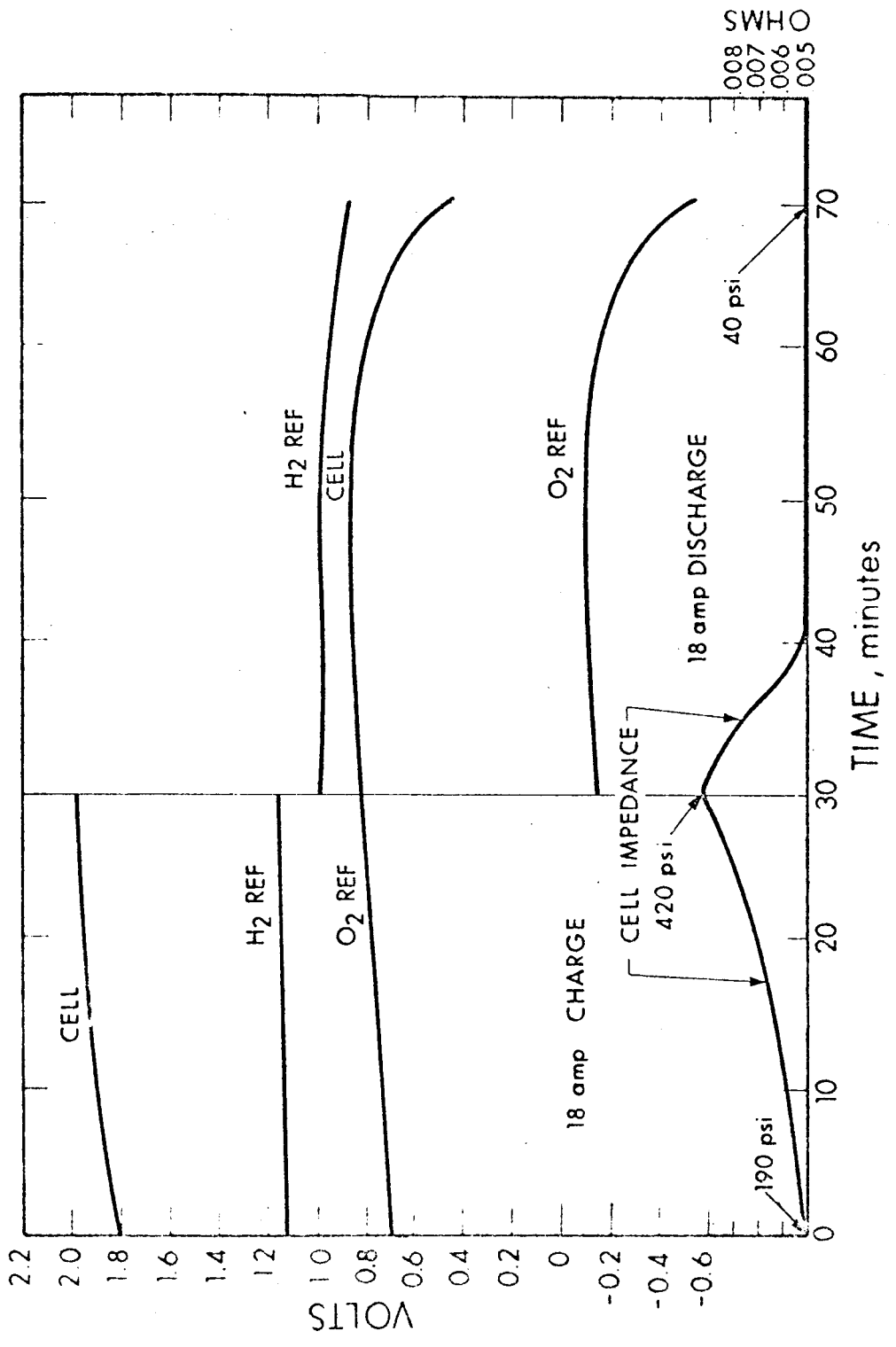


Figure 8. Reference Cell No. 280, Cycle No. 2

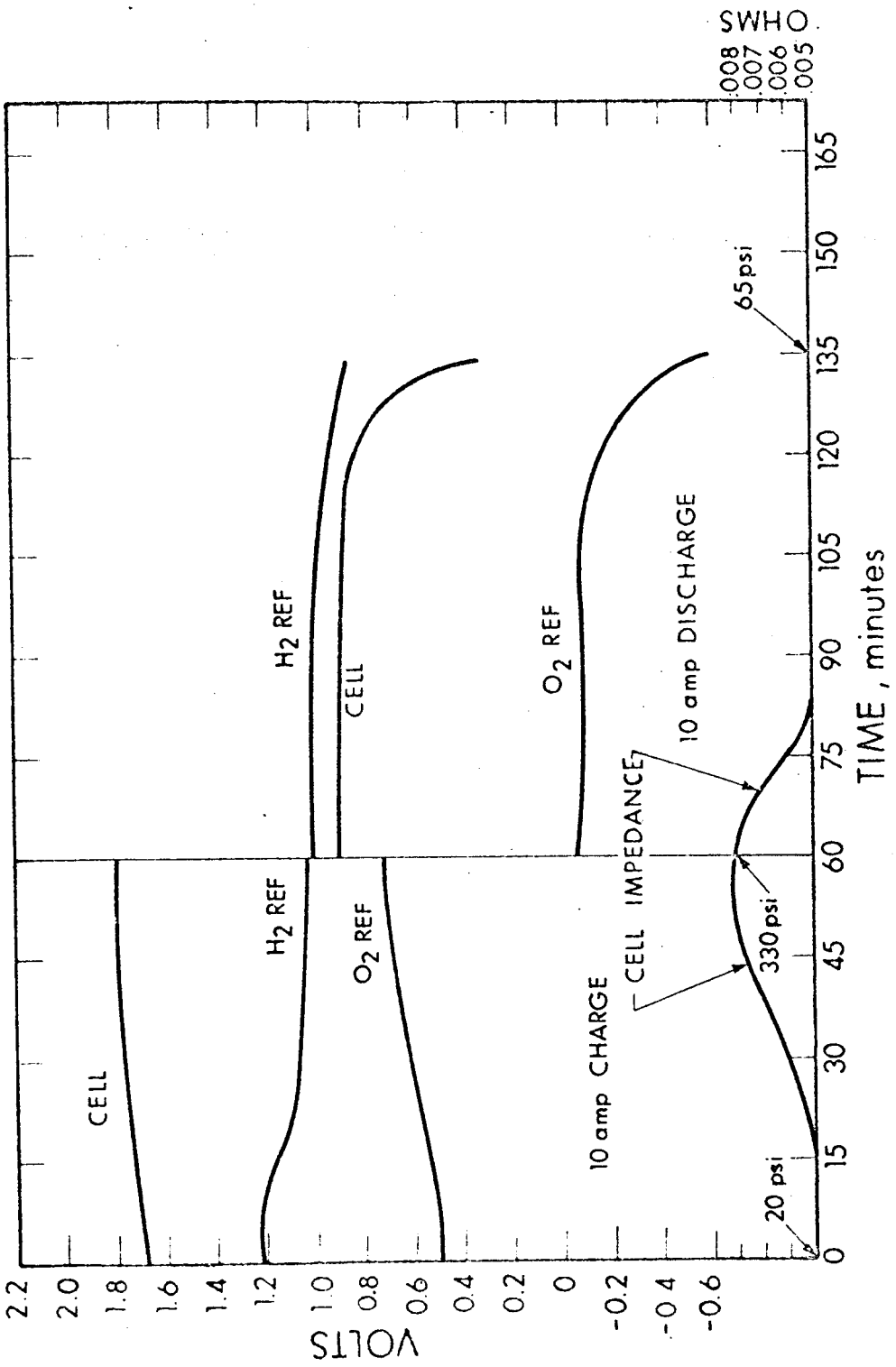


Figure 9. Reference Cell No. 280, Cycle No. 3

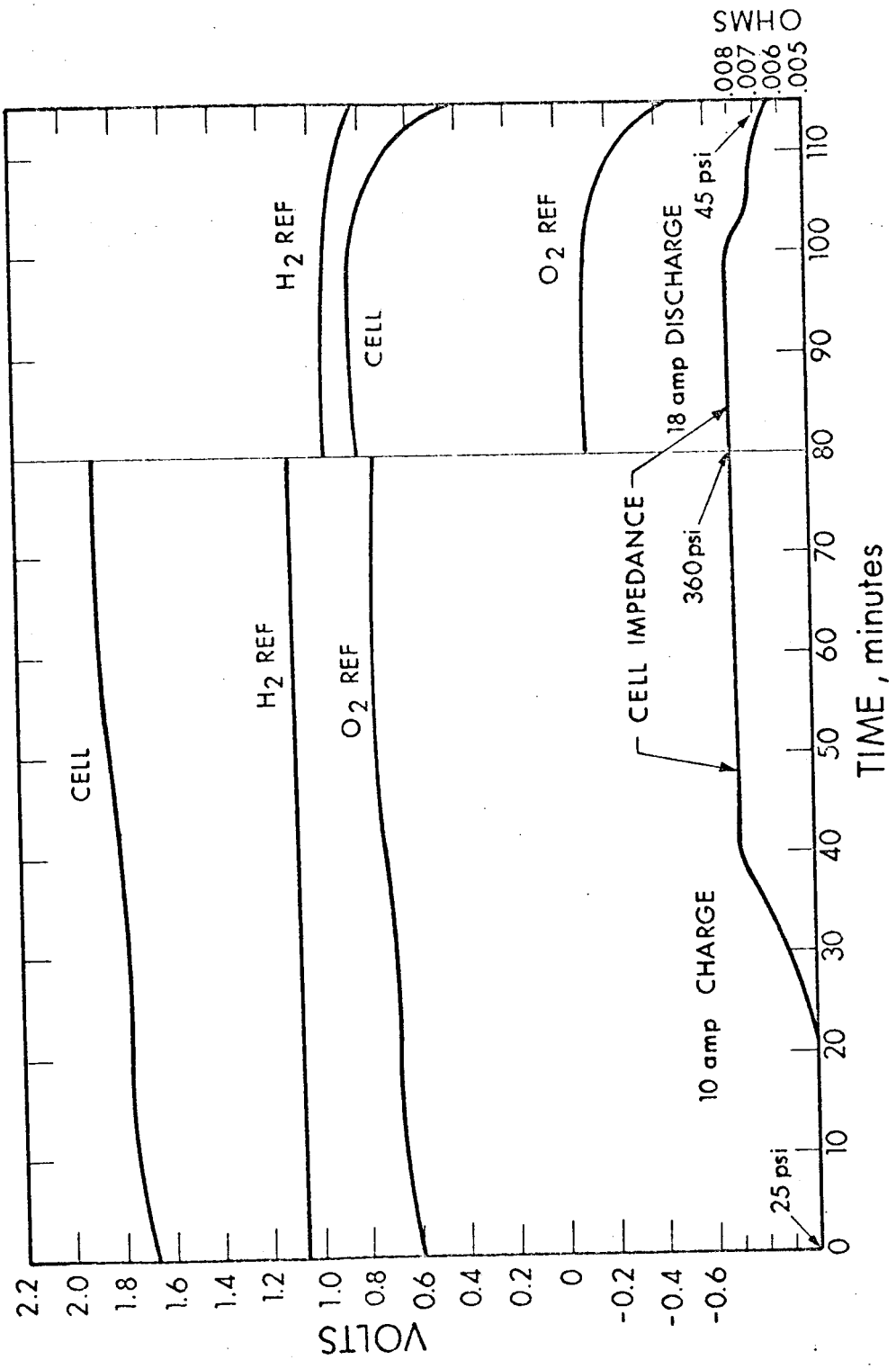


Figure 10. Reference Cell No. 280, Cycle No. 4

5% Teflon added but gave lower bubble through test results of 10 psig. This result may be caused by the mats containing Teflon being thinner. Screening work will continue on this nonasbestos composite.

TABLE II

Sample	Composition	Bubble through psig.	Resistivity -cm	Resistance	Compression psig	Thickness (wet)	Thickness (dry)
	95% KT 5% polypropylene pressed one half hour at 124 psig.	25.0	35.1	.137	0	0.070"	0.060"
			38.2	.127	178	0.060"	
			35.1	.107	188	0.055"	
			38.8	.097	284	0.045"	
			43.5	.097	284	0.040"	
			51.5	.097	284	0.034"	
			78.0	.117	284	0.027"	
M-6	90% KT 5% polypropylene 5% Teflon pressed one half hour at 124 psig.	10	55.2	.138	0	0.045"	0.040"
			53.2	.118	177	0.040"	
			45.3	.098	213	0.039"	
			40.3	.083	284	0.037"	
			36.1	.068	427	0.034"	
			38.1	.068	710	0.032"	
			40.7	.068	1142	0.030"	
M-7	90% KT 5% polypropylene 5% Teflon	10	184.0	.438	0	43	0.040"
			77.7	.168	177	39	
			51.2	.108	284	38	
			44.0	.088	356	36	
			37.6	.073	568	35	
			34.4	.063	780	33	
			45.3	.078	923	31	

SECTION 3

PLANS FOR THE NEXT PERIOD

Single cell cycling tests and laboratory screening will be continued to evaluate KT matrixes of different total weight, electrolyte-to-matrix weight ratios, thicknesses, compression ratios, and additions of asbestos, Teflon, polypropylene, and other fibers that can improve the structure of the matrix. Reference cell testing will continue. Fabrication of the 34 cell unit will continue.

SECTION 4

FINANCIAL STATEMENT

Man-hours and dollar expenditures for the period 26 May 1967 through 23 June 1967 were as follows:

Direct labor hours	689
Direct labor dollars	$3,029
Purchase and commitments	$6,803
Total dollar expenditures	$16,823